Vehicle Aggressiveness in Real World Crashes

Rory Austin
National Highway Traffic Safety Administration
United States
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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) has identified vehicle compatibility as one of its five priorities. One important component of vehicle compatibility in head-on and side impact crashes is vehicle aggressiveness. Aggressivity of a vehicle is defined as the fatality or injury risk for occupants of other vehicles with which it collides. More aggressive vehicles are more likely to produce serious injuries to occupants of the vehicles with which they collide than less aggressive vehicles. NHTSA has studied the variation in vehicle aggressiveness for over twenty five years. One recent effort using police reported crashes to understand vehicle aggressiveness was contained in the technical report "Vehicle Weight, Fatality Risk, and Crash Compatibility" by Kahane. This paper aims to validate the compatibility findings of Kahane's report by including additional years of crash data and by employing a different methodology.

Vehicle aggressiveness is determined using five years of police reported crashes from seven states in NHTSA's State Data System (SDS). The injury status of drivers in head-on crashes between a light truck or van (LTV) and a passenger car and in nearside crashes where a passenger car was struck on the left (driver's) side by another light duty vehicle are examined separately. The results demonstrate the relationship between a vehicle's aggressiveness and its body style, mass, and other physical characteristics. The robustness of the results is tested using controls for driver and crash characteristics. For the most part, the results confirm the importance of physical characteristics for understanding vehicle aggresiveness measured from police reported crashes.

INTRODUCTION

In June 2003, NHTSA released the report, "Initiatives to Address Vehicle Compatibility" [1]. This report presented an in-depth examination of the safety problem represented by vehicle incompatibility and provided strategies to improve vehicle compatibility. In addition, the background section documented over twenty five years of NHTSA research to understand and control vehicle aggressiveness. The safety problem section addressed current concerns regarding the increased exposure of car occupants to collisions with LTVs, the large and growing fatalities in collisions involving a car and an LTV, and the greater fatality risk for the car driver than the LTV driver in these collisions.

The safety assessment conclusions were further confirmed in a NHTSA report, "Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks," released in October, 2003, by Charles Kahane [2]. According to Kahane's report, LTVs were more aggressive to car drivers than other cars in head-on and nearside (left or driver's side) crashes, even when controlling for differences in vehicle weight.

Kahane also evaluated two physical parameters of vehicles derived from NHTSA's New Car Assessment Program (NCAP) frontal impact testing [3]. In nearside crashes involving an LTV and a car, Kahane found that the difference between the average height of force (AHOF) of the struck car and the striking LTV had a statistically significant negative effect on the car driver's fatality risk. Thus the more negative the difference, due either to a lower AHOF for the struck car or a higher AHOF for the striking LTV, the greater the fatality risk for the car driver. In head-on crashes involving a car and an LTV, Kahane found that the frontal stiffness of the LTV had a statistically significant positive effect on the fatality risk for the car driver.

This present study is different from Kahane's in many ways. In particular, this study predicts the probability of a serious injury or fatality given that a crash occurred rather than the fatality risk per billion miles. Instead of national fatality counts, this study focuses on police-reported crashes in seven states. Finally, the model years include vehicles from 1985 through 2002 although the analysis of physical characteristics includes mostly newer vehicles because of data availability. This study does not aim to replace or to update the "Vehicle Weight, Fatality Risk and Crash Compatibility" report but aims to serve as a complement that furthers our understanding of vehicle compatibility and aggressiveness.

DATA

This analysis uses police reported crashes from seven states in NHTSA's State Data System (SDS). The states were selected based upon the availability of vehicle identification numbers (VINs) and of initial impact points. The most recent five years of the SDS (1998 to 2002) were used in five of the states. Four years of Pennsylvania crashes were used because the 2002 file was not yet available. Three years of Kentucky crashes were used because the initial point of impact was added in 2000.

The analysis includes only light duty vehicles (vehicles with a Gross Vehicle Weight Rating of 10,000 pounds or less) as indicated by a valid VIN. Light duty vehicles include passenger cars, compact and standard pickups, utility vehicles, minivans, and large vans. Pickups, utility vehicles, and vans are also referred to as light trucks and vans or LTVs. For consistency with the VIN decoding programs decribed below, the analysis was restricted to vehicles of model year 1985 through 2003. Head-on impact crashes are defined as two vehicle crashes where the initial point of impact for both vehicles was the front (including front corners). Nearside impact crashes are defined as two vehicle crashes where the initial impact point was front for the striking vehicle and the left (driver's) side for the struck vehicle. Crashes involving a rollover or an overturned vehicle are excluded from the analysis.

Finally, the crashes of most interest in this analysis involve a car struck by a pickup, utility vehicle, or van, but the analysis includes cars struck by cars for comparative purposes. Head-on and nearside crashes involving two LTVs as well as nearside crashes where a car struck an LTV in the side are excluded. Table 1 lists the states and the years used in the analysis. The number of crashes across states differs in part because the states do not have a standard definition of impact points. These differences are controlled in later analysis by using state indicator variables.

The state files provided information about all of the drivers involved in the crash including injury severity, age, and gender. While the definition of injury severity differed across the states, this paper defines seriously injured drivers to include fatalities as well as survivors with injuries of the highest severity level noted on the police report (usually incapacititating injuries). Age is divided into four categories for analysis purposes: 14 to 29 years old, 30 to 49 years old, 50 to 69 years old, and 70 years old or older. These categories are the same as those used in the "Vehicle Weight, Fatality Risk and Crash Compatibility" report.

Table 1.
State Data System (SDS) files used in analysis

State	Years	Head-on Crashes	Nearside Crashes
LTV strikes Car			
Florida	1998-2002	22,818	15,054
Illinois	1998-2002	39,790	9,438
Kentucky	2000-2002	11,791	3,259
Maryland	1998-2002	7,845	4,305
Missouri	1998-2002	12,649	8,947
Pennsylvania	1998-2001	16,752	5,925
Wyoming	1998-2002	1,622	546
Car strikes Car			
Florida	1998-2002	28,512	45,692
Illinois	1998-2002	56,844	29,807
Kentucky	2000-2002	12,421	8,747
Maryland	1998-2002	11,010	14,173
Missouri	1998-2002	14,066	25,680
Pennsylvania	1998-2001	21,546	17,911
Wyoming	1998-2002	1,219	1,173
TOTAL		258,885	190,657

Two additional crash variables are derived from the state files. First, an indicator variable was created that identifies crashes where the speed limit was 50 miles per hour (mph) or higher. In Pennsylvania, the variable indicates whether any of the roads had a speed limit of 50 mph or higher. A second indicator variable identifies crashes where any of the drivers involved may have been impaired by alcohol or drugs.

One variable that is not used in this analysis is restraint or belt use. Belt use derived from police-reported crashes is believed to have large measurement error. The belt use in police-reported crashes in these states is larger than the estimates of belt use based upon observations from NHTSA's National Occupant Protection Use Survey (NOPUS). Furthermore, many of the states report more cases of unknown belt usage than cases of unbelted drivers. Finally, uninjured and less severely injured drivers may be more likely to overreport belt usage than more severely injured drivers. Given the large and potentially non-random measurement error in belt usage, it is not included in this analysis. However, many of the other explanatory variables (age, sex, crashes involving impaired drivers, and even state) may partially capture the effects of belt usage because they are correlated with restraint use [4].

NHTSA staff developed a series of programs to identify a vehicle's make, model, model year, LTV type, and air bag availability based upon the VIN. This analysis uses the latest version of these programs, which decode VINs of light duty vehicles from model year 1985 through 2003. The output from these programs was used to create an indicator for the presence of a driver-side front airbag, to calculate the age of the vehicle at the time of the crash, and to assign a vehicle type of car, compact pickup, standard pickup, minivan, full-size van, or utility vehicle.

These programs also assign a four-digit code that identifies a fundamental vehicle group. These groups contain all vehicles of the same type and wheelbase that run for several model years until they are redesigned. These vehicle groups are important for identifying when a vehicle parameter for one model year may be applied to other model years of the same make and model as well as across similar vehicles with different names (corporate twins).

This analysis also makes use of three vehicle parameters from NHTSA's compliance and crash tests to help explain the likelihood of a serious injury: curb weight, average height of force (AHOF), and front-end stiffness. The vehicle weights are from Federal Motor Vehicle Safety Standard (FMVSS) No. 208 and No. 301 compliance tests as well as U.S. New Car Assessment Program (NCAP) crash tests. The vehicle weights were supplemented by curb weights for model year 1991 through 1999 from the "Vehicle Weight, Fatality Risk, and Crash Compatibility" report. The additional curb weights, which predominatly came from manufacturers' reports, were adjusted to adjust for differences between reported and actual curb weights as described in Kahane's report [3, p. 19].

Average height of force and front-end stiffness are derived from frontal NCAP barrier testing. AHOF is the weighted average of the height of the applied force measured by load cells at various height levels. Front-end stiffness is the average slope of the force-deflection profile measured by the load cells. Table 2 contains some descriptive statistics for curb weight, AHOF, and stiffness.

Table 2.
Vehicle parameters by vehicle type

Vehicle Type	Curb Weight (pounds)	AHOF (mm)	Stiffness (Newtons per mm)
Car	3,072	442	1,124
Compact Pickup	3,316	511	2,299
Standard Pickup	4,927	528	2,244
Utility	3,985	531	2,200
Minivan	3,917	491	1,854
Full-size Van	5,057	551	2,628

METHODS

The unit of analysis in this study is the two vehicle crash. For nearside crashes, the dependent or prediction variable is whether the car driver, struck on the nearside by either another car or an LTV, experienced a serious injury (fatal or incapacitating). For head-on crashes, there is no clear struck or striking vehicle. In a head-on crash involving an LTV and a car, the dependent variable is whether the car driver experienced a serious injury. For head-on crashes involving two cars, one of the drivers was selected at random, and the dependent variable is whether the randomly chosen driver experienced a serious injury.

The decision to select one driver at random involves both disadvantages and advantages. The major disadvantage is that it discards the injury data for the other driver. The advantage is that it simplifies the statistical modeling. The injury information for both drivers in a head-on crash does not represent two independent observations but rather two outcomes from the same event. Therefore, the error structure of the prediction model would need to account for the expected correlation of unmeasured factors that are experienced by both drivers in the same crash. Choosing one driver eliminates the need to adopt a more complicated, and potentially less robust, statistical model. Additionally, the focus of this paper is LTV versus car crashes with the car to car crashes, of which there are a relatively large number, included only for comparison purposes.

The statistical method employed in this paper is logistic regression. Logistic regression parallels linear regression analysis where the dependent variable is a linear function of the explanatory or independent variables. However, the dependent variable in a logistic regression is the natural log of the ratio of the probability of an event occurring to the probability of the event not occurring, which is also called the log odds ratio. In this study, the dependent variable is the natural log of the ratio of the probability of the car driver experiencing a serious injury to the probability of the car driver **not** experiencing a serious injury.

The coefficients produced by the model estimation provide an estimate of the effect of a one unit change in the independent variable on the natural log of the odds ratio of experiencing a serious injury, which is not a conventional way of framing effects. However, the odds ratio can be found by taking Euler's constant (e) raised to the power of the coefficient, which is easier to interpret because it indicates how the odds of an event occurring change as you change the independent variable by one unit. If an odds ratio is less than one, it suggests that an increase in the independent variable decreases the odds of the event occurring by decreasing the probability of the event. If the odds ratio is greater than one, it suggests that an increase in the independent variable increases the odds of the event occurring by increasing the probability of the event. If the odds ratio is equal to one, it indicates that the independent variable has no effect on the likelihood of the event occurring because the probability of the event occurring did not change. Odds ratios for each independent variable are presented in the tables of results.

Logistic regression also enables tests of whether the effect of an explanatory variable on the likelihood of a serious injury is statistically significant (unlikely to have occurred by chance or randomness). The test statistic is Chi-square, and statistical significance (stat. sig.) is the probably of a Chi-square of a particular value occurring given the null hypothesis assumption that the independent variable has no effect. A sufficiently low probably, usually below 0.05, would lead us to reject the null hypothesis in favor of the alternative that the independent variable has some effect.

RESULTS

This section contains the results of logistic regression models that predict serious injury to car drivers. The results for head-on crashes are presented first, followed by the results for nearside crashes. For both types of crashes, the results begin with the most simple statistical model involving only the type of other vehicle and the state controls. The second model includes the type of other vehicle, the state variables, and driver and crash characteristics. The third model contains all of the variables in the second model plus the difference of logged vehicle weights to test whether the type of other vehicle remains a statistically significant factor. The fourth model is slightly different from the previous models because it only contains crashes involving a car and an LTV. The purpose of the fourth model is to explore vehicle parameters other than weight that may explain differences in the aggressiveness across LTV body types.

Head-on Crashes

The first logistic regression model predicts the likelihood of a serious injury to a car driver in a front to front crash with another car or an LTV. The independent variables include indicator variables for the body type of the other vehicle and for the state where the crash occurred. The results are presented in Table 3.

Cases where the other vehicle is a car were set as the base or comparison case so that the odds ratios reflect the difference in the risk of a serious injury from a crash involving an LTV relative to a car. In all cases, the car driver in a head-on crash has a statistically significant higher risk of a serious injury when the other vehicle is an LTV compared to a car. The increased risk ranges from a 30 percent higher risk when the other vehicle is a minivan to almost twice as large a risk when the other vehicle is a standard pickup. Florida was selected as the base case for the states, and the fact that most of the state variables indicate a significantly different risk confirms the importance of including state identifiers.

Table 3.
Logistic regression of serious injuries to car drivers in head-on crash by other vehicle type

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-2.822	19013	0.001	
Car	0.000			1.00
Compact Pickup	0.461	192.32	0.001	1.59
Standard Pickup	0.677	475.91	0.001	1.97
Utility Vehicle	0.335	138.08	0.001	1.40
Minivan	0.263	58.67	0.001	1.30
Full-size Van	0.434	71.08	0.001	1.54
Florida	0.000			1.00
Illinois	-0.792	966.25	0.001	0.45
Kentucky	-0.591	253.26	0.001	0.55
Maryland	-0.038	1.23	0.267	0.96
Missouri	-0.505	210.91	0.001	0.60
Pennsylvania	-1.076	820.18	0.001	0.34
Wyoming	-0.741	53.51	0.001	0.48

Note: N = 258,885; Seriously Injured = 10,956

While the above estimates provide a starting point for understanding compatibility, they do not control for other driver and crash characteristics that may explain the differences across vehicle types. The next logistic regression contains several explanatory variables in addition to the vehicle type and state indicators. The statistical model includes age categories separately for males and females. The age-gender categories of both the case vehicle and the other vehicle are likely to capture some aspects of crash severity. The age-gender categories for the case vehicle also reflect the effect of these variables on the likelihood of experiencing a severe injury [5]. Additional explanatory variables include indicators for the presence of a front driver's side airbag, for whether any of the drivers were impaired by alcohol or drugs, and whether the speed limit was 50 mph or higher. The age of the case vehicle was originally included in the model of head-on crashes, but it was dropped because its effect never achieved statistical significance. The complete results are contained in Table 4.

All of the control variables achieved statistical significance in the expected direction in the logistic regression of serious injuries to car drivers in head-on crashes by vehicle type and driver and crash characteristics. The risk of serious injury to the car driver was more than three times greater when the speed limit was 50 mph or greater and when the crash involved one or more impaired drivers. The presence of an airbag in the case car decreased the probability of a serious injury. A female driver was more likely to experience a serious injury than a male driver at all age levels, and older drivers of both genders were more likely to experience a serious injury than younger drivers. In fact, car drivers in the oldest age group (70 years old and older) were about twice as likely to experience a serious injury than the youngest age group (14 to 29 years old). The signs on the age-gender categories of the other driver were all negative and were usually statistically significant. The negative sign indicates a lower probability of a serious injury compared to the other driver being a male aged 14 to 29. This result may reflect some aspect of crash severity due to the driving behavior of the youngest males.

Even when controlling for these driver and crash characteristics, the car driver in a head-on crash still has a statistically significant higher risk of a serious injury when the other vehicle is an LTV compared to a car. The increased risk ranges from about a 30 percent higher risk when the other vehicle is a minivan to 60 percent higher when the other vehicle is a standard pickup. The lower range of risk than in the previous model is due to the explanatory power of the additional control variables.

Table 4.
Logistic regression of serious injuries to car drivers in head-on crash by other vehicle type and driver and crash characteristics

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-3.088	7040.8	0.001	
Car	0.000			1.00
Compact Pickup	0.298	73.9	0.001	1.35
Standard Pickup	0.470	202.2	0.001	1.60
Utility Vehicle	0.325	123.4	0.001	1.38
Minivan	0.273	59.7	0.001	1.31
Full-size Van	0.396	55.9	0.001	1.49
Speed limit 50 or over	1.198	2555.4	0.001	3.31
Impaired crash	1.228	1667.8	0.001	3.42
Airbag	-0.295	212.4	0.001	0.74
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.118	10.9	0.001	1.13
Male 50-69	0.221	24.9	0.001	1.25
Male 70+	0.534	109.6	0.001	1.71
Female 14-29	0.264	66.9	0.001	1.30
Female 30-49	0.459	187.2	0.001	1.58
Female 50-69	0.518	164.9	0.001	1.68
Female 70+	0.756	243.3	0.001	2.13
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.078	6.9	0.008	0.93
Male 50-69	-0.077	4.4	0.036	0.93
Male 70+	-0.077	1.8	0.175	0.93
Female 14-29	-0.174	24.6	0.001	0.84
Female 30-49	-0.185	29.7	0.001	0.83
Female 50-69	-0.085	3.5	0.063	0.92
Female 70+	-0.082	1.3	0.254	0.92
Florida	0.000			1.00
Illinois	-0.729	784.3	0.001	0.48
Kentucky	-0.767	399.7	0.001	0.46
Maryland	-0.070	3.9	0.047	0.93
Missouri	-0.609	288.8	0.001	0.54
Pennsylvania	-1.214	1007.2	0.001	0.30
Wyoming	-0.712	48.3	0.001	0.49

Note: N = 258,885; Seriously Injured = 10,956

One explanation for the higher risk of serious injury for a car driver in head-on crashes with an LTV than another car is the difference in the vehicles' masses. To test this proposition, the difference between the logged curb weight of the case vehicle and logged curb weight of the other vehicle was added to the model. (This difference is also the log of the curb weight ratio.) The natural log transformation, which was used in Kahane's study, creates a more linear relationship between weight and injury risk. The complete results are contained in Table 5.

Table 5.
Logistic regression of serious injuries to car drivers in head-on crash by other vehicle type, crash characteristics, and weight difference

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-3.102	5710.16	0.001	
Difference in logged weight	-0.842	310.46	0.001	0.43
Car	0.000			1.00
Pickup	0.171	29.28	0.001	1.19
Utility Vehicle	0.090	6.84	0.009	1.09
Minivan	0.080	3.78	0.052	1.08
Full-size Van	-0.058	0.60	0.440	0.94
Speed limit 50 or over	1.201	2112.24	0.001	3.32
Impaired crash	1.222	1310.69	0.001	3.39
Airbag	-0.274	146.06	0.001	0.76
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.137	11.62	0.001	1.15
Male 50-69	0.312	40.43	0.001	1.37
Male 70+	0.604	111.35	0.001	1.83
Female 14-29	0.218	37.29	0.001	1.24
Female 30-49	0.472	162.22	0.001	1.60
Female 50-69	0.560	159.18	0.001	1.75
Female 70+	0.825	237.83	0.001	2.28
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.120	13.65	0.000	0.89
Male 50-69	-0.143	12.24	0.001	0.87
Male 70+	-0.152	5.89	0.015	0.86
Female 14-29	-0.182	22.25	0.001	0.83
Female 30-49	-0.217	33.67	0.001	0.81
Female 50-69	-0.134	7.13	0.008	0.88
Female 70+	-0.114	2.14	0.143	0.89
Florida	0.000			1.00
Illinois	-0.732	659.55	0.001	0.48
Kentucky	-0.756	327.00	0.001	0.47
Maryland	-0.056	2.08	0.149	0.95
Missouri	-0.639	256.39	0.001	0.53
Pennsylvania	-1.251	834.66	0.001	0.29
Wyoming	-0.776	45.14	0.001	0.46

Note: N= 218,649, Seriously Injured = 9,041

The difference in curb weight has the expected strong effect. After controlling for the differences in curb weight, car drivers in a head-on crash still have a statistically significant greater risk of a serious injury when the other vehicle is a pickup or a utility vehicle than another car. The risk is also greater when the other vehicle is a minivan, but it is significant at the 0.10 level rather than the conventional 0.05 level. The difference in risk when the other vehicle is a full-size van compared to a car disappears with the addition of the curb weight variable.

The last model of the risk of serious injury to a car driver in a head-on crash includes only crashes involving a car and an LTV. The LTV body type variables are replaced with two physical LTV characteristics. One is the frontal stiffness of the LTV. The other is the difference between the average height of force of the car and the LTV. The sample size drops considerably compared to the previous models, but it remains large enough for meaningful analysis. This statistical model focuses exclusively on car-LTV head-on collisions because these variables have been shown to have different effects in car-LTV crashes than in car-car crashes. Also, full-size vans are excluded to make the results more comparable to those reported in "Vehicle Weight, Fatality Risk and Crash Compatibility." The results therefore help explain why some LTVs, particularly pickups, present a higher fatality risk to a car driver in head-on crashes than other LTVs, such as minivans, even when controlling for differences in vehicle weight. Table 6 contains the complete set of results.

Consistent with Kahane's results, LTV stiffness has a positive effect on the probability of a serious injury for the car driver in a head-on crash. The result, though, is statistically significant at the 0.10 level but not the conventional 0.05 level. The odds ratio for LTV stiffness may appear too small to indicate any explanation of LTV aggressiveness, but by definition the odds ratio indicates the change in the odds from a one unit, in this case one Newton per millimeter, increase in stiffness. If stiffness were increased 200 Newtons per mm, about 10 percent for most LTVs, the odd ratio increases to 1.01 or about a 1 percent higher risk of a serious or fatal injury. The difference in the average height of force did not have a statistically significant effect.

Table 6.
Logistic regression of serious injuries to car drivers in head-on crash with pickup, utility vehicle, or minivan by LTV characteristics

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-3.023	583.51	0.001	
Difference in logged weight	-0.682	26.94	0.001	0.51
LTV stiffness	0.000055	2.71	0.100	1.0001
Difference in AHOF	-0.000300	0.47	0.491	1.00
Speed limit 50 or over	1.133	353.87	0.001	3.11
Impaired crash	1.257	272.51	0.001	3.52
Airbag	-0.223	17.14	0.001	0.80
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.069	0.57	0.450	1.07
Male 50-69	0.156	1.75	0.187	1.17
Male 70+	0.376	7.19	0.007	1.46
Female 14-29	0.160	3.61	0.057	1.17
Female 30-49	0.484	33.01	0.001	1.62
Female 50-69	0.439	17.70	0.001	1.55
Female 70+	0.719	32.61	0.001	2.05
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.202	8.12	0.004	0.82
Male 50-69	-0.295	10.62	0.001	0.75
Male 70+	0.038	0.08	0.783	1.04
Female 14-29	-0.254	5.99	0.014	0.78
Female 30-49	-0.235	7.87	0.005	0.79
Female 50-69	-0.184	1.90	0.168	0.83
Female 70+	-0.379	1.06	0.303	0.68
Florida	0.000			1.00
Illinois	-0.731	105.09	0.001	0.48
Kentucky	-0.722	59.82	0.001	0.49
Maryland	0.040	0.19	0.664	1.04
Missouri	-0.635	46.13	0.001	0.53
Pennsylvania	-1.115	126.00	0.001	0.33
Wyoming	-0.495	3.89	0.048	0.61

Note: N = 32,640, Seriously Injured = 1,615

Nearside Crashes

Statistical models similar to those used to predict serious injuries to a car driver in head-on crashes were also applied to estimating the probability of a serious injury for a car driver struck on the left side (nearside) by the front of another vehicle. The first model contains the type of striking vehicle and the state indicators. Once again the car is the base or comparison striking vehicle type. The results are contained in Table 7.

Table 7.
Logistic regression of serious injuries to car drivers in nearside crash by other vehicle type

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-2.784	24215	0.001	
Car	0.000			1.00
Compact Pickup	0.670	244.86	0.001	1.96
Standard Pickup	1.020	780.95	0.001	2.77
Utility Vehicle	0.712	411.50	0.001	2.04
Minivan	0.378	62.17	0.001	1.46
Full-size Van	0.748	163.86	0.001	2.11
Florida	0.000			1.00
Illinois	-0.758	565.31	0.001	0.47
Kentucky	-0.723	203.30	0.001	0.49
Maryland	-0.046	1.93	0.164	0.96
Missouri	-1.001	768.19	0.001	0.37
Pennsylvania	-1.095	614.42	0.001	0.34
Wyoming	-1.118	56.06	0.001	0.33

N = 190,657, Seriously Injured = 9,059

In all cases, the car driver in a nearside crash has a statistically significant higher risk of a serious injury when the striking vehicle is an LTV compared to a car. The increased risk ranges from about a 50 percent higher risk when the other vehicle is a minivan to almost three times as large a risk when the other vehicle is a standard pickup.

The next statistical model includes the various driver and crash characteristics. There is only a small change from the model of the likelihood of serious injury in head-on crashes to the model in nearside crashes. The airbag variable, which indicated a front airbag for the driver, is dropped, but the presence of side impact airbags is not readily available. Instead, the age of the struck vehicle is added to the models. This variable, which was not included in the head-on models because it never achieved statistical significance, does achieve statistical significance in the nearside models. Otherwise, the explanatory variables are the same as those described previously. The complete results for the logistic regression model of serious injuries to car drivers struck on the nearside by vehicle type and driver and crash characteristics are included in Table 8.

Table 8.
Logistic regression of serious injuries to car drivers in nearside crash by other vehicle type and driver and crash characteristics

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-3.327	5935.27	0.001	
Car	0.000			1.00
Compact Pickup	0.530	143.90	0.001	1.70
Standard Pickup	0.862	500.68	0.001	2.37
Utility Vehicle	0.681	361.91	0.001	1.98
Minivan	0.366	55.80	0.001	1.44
Full-size Van	0.706	139.07	0.001	2.03
Speed limit 50 or over	0.929	1149.44	0.001	2.53
Impaired crash	0.801	403.95	0.001	2.23
Vehicle age	0.027	101.81	0.001	1.03
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.041	0.97	0.325	1.04
Male 50-69	0.202	17.46	0.001	1.22
Male 70+	0.907	350.12	0.001	2.48
Female 14-29	0.375	96.04	0.001	1.46
Female 30-49	0.451	136.32	0.001	1.57
Female 50-69	0.690	244.10	0.001	1.99
Female 70+	1.048	439.58	0.001	2.85
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.130	16.42	0.001	0.88
Male 50-69	-0.204	24.10	0.001	0.82
Male 70+	-0.289	22.98	0.001	0.75
Female 14-29	-0.239	43.54	0.001	0.79
Female 30-49	-0.196	29.02	0.001	0.82
Female 50-69	-0.291	33.63	0.001	0.75
Female 70+	-0.266	15.28	0.001	0.77
Florida	0.000			1.00
Illinois	-0.737	521.29	0.001	0.48
Kentucky	-0.858	277.14	0.001	0.42
Maryland	-0.091	7.15	0.008	0.91
Missouri	-1.094	881.74	0.001	0.34
Pennsylvania	-1.222	747.15	0.001	0.30
Wyoming	-1.112	54.96	0.001	0.33

Note: N = 190,657, Seriously Injured = 9,059

Table 8 indicates that the age-gender categories, the impaired crash indicator, and the speed limit of 50 mph or higher all have the expected statistically significant effects. Vehicle age also has a statistically significant effect such that the struck driver in an older vehicle has a higher risk of serious injury than a struck driver in a newer vehicle. Even with these additional control variables, the struck car driver still has a statistically significant higher risk of a serious injury when the other vehicle is an LTV compared to a car. The increased risk ranges from about 44 percent higher risk when the other vehicle is a minivan to over twice the risk when the other vehicle is a standard pickup than a car. The control variables do not appear to diminish the estimated aggressiveness of LTVs in nearside impacts as much as it was diminished in head-on crashes.

The third statistical model of the risk of serious injury to car drivers struck on the nearside adds the difference in the logged curb weights. The complete results of the model are contained in Table 9. The difference in curb weight has a strong effect on the probability of the struck driver experiencing a serious injury. Once the control for the difference in the weights is included, both striking minivans and full-size vans are no longer statistically different from striking cars in terms of the risk of serious injury experienced by the nearside struck car driver. However, car drivers struck on the nearside still have a statistically significant greater risk of a serious injury when the other vehicle is a pickup or a utility vehicle than a car.

The final model contains just car drivers struck on the nearside by pickups, utility vehicles, and minivans for the reasons discussed in the head-on crash section. The complete results are in Table 10 and are again consistent with the findings in Kahane's report. While the striking vehicle's stiffness did not have a statistically significant effect on the probability of serious injury for the struck car driver, the striking vehicle's average height of force did have a statistically significant effect. The odds ratio for AHOF may appear too small to indicate any explanation of LTV aggressiveness, but by definition the odds ratio indicates the change in the odds from a one unit, in this case one millimeter, increase in AHOF. An increase in the average height of force of 50 mm, about 10 percent for most LTVs, increases the risk of serious injury by about 7 percent. This relationship may be even stronger if the statistical model accounted for characteristics of the side of the struck vehicle such as side sill height, but it is still a strong predictor even without this additional information.

Table 9.
Logistic regression of serious injuries to car drivers in nearside crash by other vehicle type, crash characteristics, and weight difference

Variable	Coef-ficient	Chi-Square	Stat. Sig.	Odds Ratio
Intercept	-3.237	4714.84	0.001	
Difference in logged weight	-1.059	478.96	0.001	0.35
Car	0.000			1.00
Pickup	0.390	112.14	0.001	1.48
Utility Vehicle	0.337	65.66	0.001	1.40
Minivan	0.047	0.69	0.405	1.05
Full-size Van	0.112	1.94	0.163	1.12
Speed limit 50 or over	0.965	1047.25	0.001	2.63
Impaired crash	0.838	361.61	0.001	2.31
Vehicle age	0.026	71.78	0.001	1.03
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.104	5.24	0.022	1.11
Male 50-69	0.319	36.12	0.001	1.38
Male 70+	0.999	349.00	0.001	2.71
Female 14-29	0.302	51.82	0.001	1.35
Female 30-49	0.453	114.67	0.001	1.57
Female 50-69	0.734	233.38	0.001	2.08
Female 70+	1.110	411.82	0.001	3.03
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.202	32.77	0.001	0.82
Male 50-69	-0.281	37.88	0.001	0.76
Male 70+	-0.419	40.09	0.001	0.66
Female 14-29	-0.217	30.42	0.001	0.81
Female 30-49	-0.257	41.38	0.001	0.77
Female 50-69	-0.352	42.02	0.001	0.70
Female 70+	-0.317	19.03	0.001	0.73
Florida	0.000			1.00
Illinois	-0.770	479.26	0.001	0.46
Kentucky	-0.864	240.96	0.001	0.42
Maryland	-0.136	13.32	0.001	0.87
Missouri	-1.110	756.01	0.001	0.33
Pennsylvania	-1.247	626.41	0.001	0.29
Wyoming	-1.151	46.22	0.001	0.32

Note: N = 159,477, Seriously Injured = 7,623

Table 10.
Logistic regression of serious injuries to car drivers in nearside crash with pickup, utility vehicle, or minivan by LTV characteristics

Variable	**Coef-ficient**	**Chi-Square**	**Stat. Sig.**	**Odds Ratio**
Intercept	-3.646	120.07	0.001	
Difference in logged weight	-0.911	46.53	0.001	0.40
Striking LTV stiffness	0.00003	0.82	0.365	1.000
Striking LTV AHOF	0.00133	4.75	0.029	1.001
Speed limit 50 or over	1.044	224.06	0.001	2.84
Impaired crash	0.983	91.90	0.001	2.67
Vehicle age	0.023	9.23	0.002	1.02
This driver				
Male 14-29	0.000			1.00
Male 30-49	0.067	0.35	0.556	1.07
Male 50-69	0.471	13.43	0.000	1.60
Male 70+	1.112	74.63	0.001	3.04
Female 14-29	0.272	7.32	0.007	1.31
Female 30-49	0.322	9.38	0.002	1.38
Female 50-69	0.545	21.07	0.001	1.72
Female 70+	1.007	61.08	0.001	2.74
Other driver				
Male 14-29	0.000			1.00
Male 30-49	-0.191	6.01	0.014	0.83
Male 50-69	-0.304	9.03	0.003	0.74
Male 70+	-0.278	2.56	0.110	0.76
Female 14-29	-0.380	9.62	0.002	0.68
Female 30-49	-0.163	2.98	0.084	0.85
Female 50-69	-0.232	2.26	0.133	0.79
Female 70+	-0.547	1.88	0.170	0.58
Florida	0.000			1.00
Illinois	-0.810	83.39	0.001	0.45
Kentucky	-0.721	36.36	0.001	0.49
Maryland	-0.248	6.83	0.009	0.78
Missouri	-0.999	115.76	0.001	0.37
Pennsylvania	-1.134	102.86	0.001	0.32
Wyoming	-1.623	10.03	0.002	0.20

Note: N = 18,105, Seriously injured = 1,316

CONCLUSIONS

The findings in this paper are consistent with many of NHTSA's previous studies regarding vehicle compatibility and aggressiveness in head-on and nearside crashes [2, 3, 6, 7, 8] even though the methodology is quite different. The risk of a serious injury to a car driver struck head-on or struck on the nearside by an LTV is higher than when struck by another car even when controlling for driver and crash characteristics. Aggressiveness differs across LTVs with minivans at the lower end, utility vehicles in the middle, and standard pickups at the high end. These results are similar but do not exactly correspond to previous agency research. For example, the order from least to most aggressive LTV type in head-on crashes from "NHTSA's Research Program for Vehicle Compatibility" was compact pickup, minivan, small utility, large utility, large van, and large pickup [6, p. 2]. For side impact crashes, the order from least to most aggressive was minivan, compact pickup, small utility, large van, large pickup, and large utility [6, p. 3]. In this present study, the compact pickups tended to look more similar to utility vehicles than minivans in terms of aggressiveness.

When taking differences in curb weight into account, the aggressiveness of minivans and full-size vans disappears in nearside crashes and almost disappears in head-on crashes. This finding is similar to results presented in Kahane's study, which found that the higher aggressiveness of minivans compared to cars was no longer statistically significant when controlling for differences in vehicle weight. However, Kahane found that utility vehicles were more aggressive than pickups after controlling for weight while this study generally indicates that pickups were the most aggressive LTV category [2, pp.254-55].

For pickups and utility vehicles, curb weight alone does not explain the higher risk of serious injury to car drivers struck head-on or on the nearside. Among pickups, utility vehicles, and minivans, the average height of force explains why some of these vehicles are related to a higher risk of serious injury for a car driver struck on the nearside, and the stiffness of the LTV explains why some of these vehicles are related to higher risk of serious injury for a car driver struck head-on. These findings are consistent with the results presented in Kahane's report even though they are not exactly the same. In head-on crashes between an LTV and a car, Kahane found that the natural log of the LTV stiffness was a statistically significant predictor of the car driver's fatality risk. In nearside crashes where the front of an

LTV struck the left side of a car, Kahane found that the difference in the average height of force of the two vehicles was a statistically significant predictor of car driver's fatality risk [6, p.268]. This paper indicates similar results with the exception that the LTV stiffness itself, rather than the natural log of stiffness, was statistically significant. This paper also uses the LTV's AHOF in the nearside impact models rather than the difference in AHOF because of questions raised (and noted in Kahane's report) about the use of the car's AHOF as a surrogate for sill height.

Although these results do reinforce many of Kahane's findings, the results from a paper by Stephen Summers and Aloke Prasad prepared for the 19th Technical Conference on the Enhanced Safety of Vehicles (ESV) do not validate the findings in the laboratory. Summers and Prasad describe the results from three sets of vehicle-to-vehicle crash tests (full frontal, frontal 50% offset, and side impact) involving an LTV striking a car. According to their paper, "none of the three test series provided significant insight or understanding to explain the fleet correlations with stiffness and AHOF metrics" [9, p. 14].

Summers and Prasad suggest a couple of reasons why the results from statistical studies using police reported crashes, such as this paper and Kahane's study, may not be supported by laboratory crash tests. One reason may be that the crash severity in the laboratory tests may not be representative of the crash severity necessary for compatibility to play a significant role in the fleet data. It may be the case that aggressiveness is more apparent in high delta-V crashes, which are also the crashes that are most likely to produce serious injuries and fatalities, than in lower delta-V crashes. Another reason may be that the laboratory testing used a model year 2004 car while the statistical studies use historical data that includes vehicles as old as model year 1985. Therefore, statistical studies such as this one may not capture the most recent changes in vehicle design. In particular, changes in restraint systems, such as the addition of side curtain air bags, may help explain why the most current laboratory testing do not explain the fleet differences. Another reason not mentioned in the Summers and Prasad paper may be that the laboratory testing involved only one car model. It may be the case that LTV aggresiveness is more of an issue for some cars than for others.

Even in the crash data, the relationships between vehicle metrics and aggressiveness appear to be only part of the explanation. One reason is that the statistical noise in real world crashes may never be perfectly captured by explanatory variables. At the same time, increased attention to the accurate measurement and perhaps refinement of the physical characteristics of the vehicles, as well as the exploration of additional parameters, may increase our understanding of vehicle aggressiveness. Finally, future statistical studies should, as much as possible, explore the role played by vehicle design changes and improvements in restraint systems in predicting vehicle aggressiveness.

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